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European sovereign debt crisis and linkage of long-term government bond yields

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Abstract

Based on the robust cross-correlation function approach developed by Hong (2001), this paper investigates the causality-in-mean and the causality-in-variance of long-term bond yields in seven countries including "PIIGS" (Portugal, Ireland, Italy, Greece, and Spain), Germany, and France. A main contribution of the study is to assess the impacts of the recent European sovereign debt crisis on relationships of the bond yields. We find some evidence of the mean spillover effects, especially from Portugal and France before the crisis and from Portugal and Italy after the crisis. In contrast, the variance spillover effects from Germany interestingly strengthened through the debt crisis in particular despite the apparent lack of its mean transmission effects, whilst major sources of volatility spillover effects had been Portugal and France prior to the crisis.

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1. Introduction

This paper sheds light on the volatility spillover effects of long-term bond yields among the seven European countries using the Hong (2001) causality-in-variance test. Concerns over sovereign risks of Greece, first triggered by the downgrade of its credit rating in late 2009, have spread to Ireland and Portugal, leading the countries to face sharp increases in the government bond yields and finally ask for financial support from the European Union and IMF. Historically, high risks of sovereign debts had been associated with emerging countries. An interesting fact about the recent European sovereign debt crisis is that the risks were realized in relatively advanced economies such as Greece, Ireland, and Portugal. Hence, an investigation on dynamic relationships across those government bond markets will provide policymakers not only in Europe but also in the US and Japan, suffering from high debt-to-GDP ratio, with some insights into how contagion of sovereign risks is spread across markets.

Although there are a large number of literatures conducted to analyze linkages of global equity markets, only a few studies examine those in international bond markets. Using the Johansen method for six major government bond markets, Smith (2002) reports evidence on integration. Barr and Priestley (2004) use a conditional asset pricing model with variation in prices and quantities of the risk and finds partial integration among the five world government bond indices. Yang (2005), studying monthly data, shows that six major European bond markets (Germany, France, Italy, UK, Belgium, and the Netherlands) have Granger causality at least in the short run. Using similar dataset, Christiansen (2007) and Christiansen (2010) demonstrate the volatility spillover effects from US and European bond markets into each of national European bond markets and that after the introduction of the euro the EU's bond markets have become more integrated than its stock markets. Contrary to these previous literatures, Li et al (2008) is found to be the only study testing the causality-in-variance of monthly bond indices using the cross-correlation function proposed by Hong (2001). They show that causality-in-variance exists among bond index returns in the short run.

In the assessment of volatility spillover, we think analyzing causality-in-variance is crucial because it exists among markets even though those returns apparently do not exhibit causality-in-mean. As shown in Ross (1989), volatility contains useful data on information flow, and hence, deeper look at directions and lags of volatility transmission will enable market participants investing across multiple assets and various countries to adjust their asset allocation appropriately.

We extend the literatures of tests for linkages of international bond markets using the Hong (2001) approach, similar to Li et al (2008). To our best knowledge, however, this is the first study to evaluate the impacts of the recent European sovereign debt crisis on relationships among the long-term bond yields. We divide the whole sample into two and show the significant changes in direction and magnitude of spillover effects both in terms of mean and variance through the sovereign debt crisis.

The rest of the paper is organized as follows. Section 2 presents the methodology used in our study. Section 3 explains details of our dataset. Section 4 provides our model specification and empirical results of the causality tests. Finally, in Section 5, a brief summary of our findings is shared.

2. Methodology

Cheung and Ng (1996) first proposed a test to examine directional relationships of volatility spillover across different markets. Its approach follows a two-step procedure. First, each data is fitted to a univariate time-series model with time variation in the conditional variance. Second, causality-in-variance is analyzed using cross-correlation function (CCF) between two squared residuals, each standardized by their conditional variance estimators. Let us denote two stationary time series by X_t and Y_t. Also, three information sets are denoted by

$$I_{1t} = \{X_{t-j}; j \geq 0\}, I_{2t} = \{Y_{t-j}; j \geq 0\}, \text{ and } I_t = \{X_{t-j}, Y_{t-j}; j \geq 0\}. \tag{1}$$

Suppose also that $\mu_{X,t}$ and $\mu_{Y,t}$ denote the mean of X_t conditioned on I_{1t} and of Y_t conditioned on I_{2t}, respectively. We say that Y_t causes X_t in variance if

$$E[(X_t - \mu_{X,t})^2 \mid I_{1,t-1}] \neq E[(X_t - \mu_{X,t})^2 \mid I_{t-1}], \tag{2}$$

while X_t causes Y_t in variance if

$$E[(Y_t - \mu_{Y,t})^2 \mid I_{2,t-1}] \neq E[(Y_t - \mu_{Y,t})^2 \mid I_{t-1}]. \tag{3}$$

The S-statistic used in the causality-in-variance test is based on the sum of the first k squared cross-correlations:

$$S = T \sum_{i=1}^{k} \hat{r}_{uv}^{2}(i) \xrightarrow{L} \chi^2(k) \tag{4}$$

where

$$\hat{r}_{uv}(i) = \{c_{uu}(0) c_{vv}(0)\}^{-1/2} c_{uv}(i), \tag{5}$$

$$c_{uv}(k) = T^{-1}\sum_{t=1}^{T-k}(\hat{u}_t - \bar{u})(\hat{v}_{t+k} - \bar{v}) \quad \text{for k=0, 1, 2, …}$$

$$= T^{-1}\sum_{t=1}^{T-k}(\hat{u}_{t-k} - \bar{u})(\hat{v}_t - \bar{v}) \quad \text{for k=0, -1, -2, …} \tag{6}$$

$c_{uu}(0)$ and $c_{vv}(0)$: sample variances of the disturbance u_t and v_t,

$$u_t = (X_t - \mu_{X,t})^2 / h_{X,t}, \tag{7}$$

$$v_t = (Y_t - \mu_{Y,t})^2 / h_{Y,t}, \text{ and} \tag{8}$$

$h_{i,t}$: conditional GARCH(p, q) variance.

Cheung and Ng (1996) asserts that this S-statistic can be used to test the null hypothesis of no causality-in-variance from lag 1 to lag k.

One notable issue of the S-statistic is that it places weight on each lag uniformly and thus may be subject to size distortion when causality-in-mean exists. We adopt the approach suggested by Hong (2001) which incorporates the weighting cross-correlation. The one-sided causality statistic is defined as

$$Q = \frac{S-k}{\sqrt{2k}} \xrightarrow{L} N(0,1). \tag{9}$$

Applying this Q-statistic to upper-tailed N(0,1) critical values, we reject the null hypothesis of no causality-in-variance from lag 1 to lag k, if the test statistic is larger than the critical value of standard normal distribution. Similar to the S-test, this Q-test can be used to test the causality-in-mean through the process of replacing u_t and v_t by the standardized innovations such as

$$\varepsilon_t = \frac{X_t - \mu_{X,t}}{\sqrt{h_{X,t}}} \quad \text{and} \quad \varsigma_t = \frac{Y_t - \mu_{Y,t}}{\sqrt{h_{Y,t}}}. \tag{10}$$

3. Data Description

Our dataset includes 1,109 time series on long-term bond yields ranging from January 1, 2007 to March 31, 2011 for seven European countries: Portugal (PG), Ireland (IR), Italy (IL), Greece (GR), Spain (SP), Germany (GM), and France (FR). As in Gabrisch and Orlowski (2010), we obtain the data on ten-year Maastricht convergence bond yields from Eurostat in order to ensure that apple-to-apple comparison among those seven EU countries is possible. Specifically, daily data is used for our study because an issue of aggregation effects, which might be triggered by using monthly data, should be avoided, and more importantly, because with daily dataset a sufficient number of samples is available for our assessment of the relatively recent European sovereign debt crisis.

We categorize the whole sample into two sub-samples: Sample A is from January 1, 2007 to December 15, 2009, while Sample B is from December 16, 2009 to March 31, 2011. December 16, 2009 is regarded as the beginning of the crisis, because Standard & Poor's cut Greece's credit rating from A1- to BBB+ with a negative outlook on the day, triggering sale of Euro, and market participants began to keenly realize the country's structural sovereign debt issues and potential transmission of its crisis across European countries.

Table 1 contains descriptive statistics on our dataset. It should be noted that standard deviations increased through the crisis, with sharp increases observed for Portugal, Ireland, and Greece. The level of kurtosis decreased across bond yields, except for Germany and France. Jacque-Bera tests reject normality for all countries regardless of the sample periods. Augmented Dickey-Fuller (AD) tests result in identification of unit root processes for level data, but not for first-difference data at the 1% significance level. Hence, we use the first-difference data, as applied to international long-term bond yields in Alaganar and Bhar (2003).

4. Empirical Results and Discussion

AR-EGARCH specification

The first step is to model long-term bond yields for each of the seven countries. Elyasiani and Mansur (1998) and Alagnar and Bhar (2003) applied GARCH(1,1) models to international long-term bond yield datasets. A main difference used in our approach is to select and fit the best of AR(k)-EGARCH(p,q) models. In fact, the conditional mean and variance for first-difference data on the long-term bond yields, denoted by x_t, are specified as follows:

$$x_t = a_t + \sum_{i=1}^{k} a_i x_{t-i} + \varepsilon_t \tag{11}$$

$$\log(\sigma_t^2) = \omega + \sum_{i=1}^{p} (\alpha_i \left| \frac{\varepsilon_{t-i}}{\sigma_{t-i}} \right| + \gamma_i \frac{\varepsilon_{t-i}}{\sigma_{t-i}}) + \sum_{i=1}^{q} \beta_i \log(\sigma_{t-i}^2) \tag{12}$$

Choice of k (=1, 2, …, 10), p(=1, 2), and q(=1, 2) is made based on the Schwarz Bayesian information criterion (SBIC).

Table 2 and Table 3 present the empirical results for the pre- and post-crisis periods, respectively. In Sample A, we select AR(1)-EGARCH(1,1) for all of the seven countries concerned. For the variance equation, it is noticeable that all estimated parameters for the seven countries are statistically significant at the 5% significance level, except for coefficients of the asymmetric term (γ_1) which exhibits insignificance for Portugal, Ireland, Spain, Germany, and France. We think that this insignificance of the asymmetric term does not undermine the validity of using the EGARCH model, though. One concern we have to note is, however, that the mean equation does not fit well to the dataset relatively, exhibiting insignificance of coefficients of the parameter a1 for three countries including Spain, Germany, and France. $Q(20)$ and $Q^2(20)$ are the Ljung-Box statistics for the null hypothesis that no autocorrelation exists up to order 20 for standardized residuals and standard residuals squared, respectively. The p-values for $Q(20)$ and $Q^2(20)$ are larger than 0.01 for all countries, which results in our acceptance of the null hypothesis of no autocorrelation. In Sample B, we see that AR(1)-EGARCH(1,1) is chosen for all of the seven countries, as in Sample A. Again, in terms of the variance equation, all estimated parameters for all the countries are statistically significant at the 5% significance level, except for coefficients of the asymmetric term (γ_1) on Greece, Germany, and France and the asymmetric term (α_1) on Ireland and Italy. The p-values for $Q(20)$ and $Q^2(20)$ are larger than 0.01 for all nations; thus, the null hypothesis of no autocorrelation up to order 20 for both standardized residuals and standard residuals squared is accepted. These results indicate that our AR-EGARCH models fit to the dataset reasonably well.

Tests of causality-in-mean and causality-in-variance

Our second step is to test for the causality-in-mean and causality-in-variance using the weighted cross-correlation functions of standard residuals and standard residuals squared. Table 4 through Table 10 present the Hong's Q-statistics to test the null hypothesis of no causality from lag 1 to lag k (=5, 10, 15), measured in days, for each unidirectional combination of the seven countries.

In terms of causality-in-mean, we find that during the pre-crisis period Portugal and France were the major sources of transmission. Nevertheless, after the sovereign debt crisis, a visible decrease in the mean spillover effects was identified especially for France. France, once having affected all other countries (lag 5, 10, 15) except Portugal and Ireland at the 1% significance level, had mean transmission effects only on Germany (lag 5, 10, 15) at the 1% significance level and on Ireland (lag 5) at the 5% significance level during the post-crisis period. In contrast, Portugal remained to be a main source of transmission, affecting Greece and Spain (lag 5, 10, 15) and Ireland and Italy (lag 5) both at the 1% significance level. It is interesting to note that Italy, once having had effects on Spain and Greece, began to cause mean transmission effects on countries suffering from issues in creditworthiness of sovereign debts, namely Portugal (lag 5, 10) and Ireland (lag 5) at the 1% significance level.

The causality-in-variance prior to the debt crisis had also been evident in Portugal (affecting Greece, Spain, and Germany) and France (affecting Ireland Greece, Spain, and Germany) both at the 1% significance level. In turn, during the post-crisis period the reduction of the effects from Portugal was found, while France remained to be a main source of the causality-in-variance. Noteworthy increases in volatility spillover effects occurred in Germany. Germany, which had exerted nearly no influence except on Italy (lag 15), began to trigger transmission to Portugal, Ireland, Italy and Spain (lag 5, 10, 15) at the 1% significance level and also to Greece (lag 5) and France (lag 10) at the 5% significance level. In contrast, even during the post-crisis period, Greece exerted influences in the causality-in-variance only on Italy (lag 5, 10) at the 5% significance and France (lag 10) at the 1% significance level, although the country is generally regarded as the source of concerns over creditworthiness of sovereign debts spread across Europe.

5. Conclusion

In this article, we extend the series of literatures on volatility spillovers in global bond markets with a first-time look at the impacts of the recent sovereign debt crisis having occurred across European “PIIGS”. We apply AR-EGARCH models to the daily data on long-term bond yields of seven European countries (Portugal, Ireland, Italy, Greece, Spain, Germany, and France) during the period of January 2007 and March 2011, and then use the robust cross-correlation approach recently developed by Hong (2001) to investigate both the causality-in-mean and the causality-in-variance.

Our causality analysis confirms the existence of short-term mean spillover effects prevailing across all the countries, most notably seen in the effects from Portugal and France prior to the crisis and from Portugal and Italy after the crisis. Our findings also suggest that major sources of the volatility spillover effects were Portugal and France before the crisis occurred. After the crisis, the volatility spillover effects from Germany strengthened in particular, as opposed to relatively weak causality-in-mean effects from the country. From fund managers’ perspectives, this knowledge on recent changes in the direction of volatility spillovers, despite the apparent lack of its mean transmission effects, may be helpful when they consider diversification strategies. Specifically, Germany has been seen as an outstanding country in terms of its creditworthiness driven by sound fiscal policies, compared to those of European "PIIGS" suffering from high debt-GDP ratio. However, the volatility spillover effects from Germany on long-term bond yields of other countries, which have emerged during the post-crisis period, should not be ignored when considering diversification in European government bond markets.

We recognize that due to its focus on the recent sovereign debt crisis, this paper does not explicitly analyze impacts of the 2007-2008 US sub-prime loan crises which might fundamentally alter the linkages among European bond markets as well. Careful choice of sample periods and lags might allow us to study the fundamental impacts in longer time horizon. Addressing this issue is left for our future research.

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Table 1. Descriptive statistics of 10Y Maastricht convergence bond yields

Sample A: (Jan 1, 2007 - Dec. 15, 2009)

	PG	IR	IL	GR	SP	GM	FR
Mean (percent)	4.39	4.68	4.50	4.81	4.22	3.82	4.07
Median (percent)	4.42	4.56	4.48	4.68	4.22	3.98	4.11
Maximum (percent)	5.10	6.30	5.29	6.19	4.96	4.67	4.84
Minimum (percent)	3.73	3.90	3.95	4.13	3.65	2.87	3.35
Std. Dev. (percent)	0.30	0.50	0.27	0.44	0.29	0.50	0.37
Skewness	-0.16	0.89	0.40	0.84	0.20	-0.28	-0.04
Kurtosis	2.51	3.12	3.03	3.06	2.43	1.73	1.95
Jarque-Bera	11.07	101.76	20.29	91.19	15.84	61.77	35.96
Num. of obs.	772	772	772	772	772	772	772

Sample B: (Dec. 16, 2009 - Mar. 31, 2011)

	PG	IR	IL	GR	SP	GM	FR
Mean (percent)	5.73	6.39	4.18	9.52	4.44	2.83	3.21
Median (percent)	5.69	5.49	4.04	10.29	4.15	2.93	3.35
Maximum (percent)	8.74	10.19	5.06	12.88	5.56	3.35	3.72
Minimum (percent)	3.87	4.44	3.71	5.54	3.76	2.06	2.47
Std. Dev. (percent)	1.17	1.84	0.36	2.32	0.59	0.35	0.33
Skewness	0.21	0.65	0.87	-0.38	0.67	-0.37	-0.51
Kurtosis	1.93	1.80	2.34	1.66	1.86	1.79	2.00
Jarque-Bera	18.52	43.75	48.84	33.15	43.72	28.23	28.49
Num. of obs.	337	337	337	337	337	337	337

Note: Statistics for level data on each of the bond yields are reported.
Countries are abbreviated as follows; PG (Portugal), IR (Ireland), IL (Italy), GR (Greece), SP (Spain), GM (Germany), FR (France).

Table 2. AR-EGARCH models - Sample A (Jan 1, 2007 - Dec. 15, 2009)

	Model by Country													
	PG		IR		IL		GR		SP		GM		FR	
	AR(1)EGARCH(1,1)		AR(1)EGARCH(1,1)		AR(1)EGARCH(1,1)		AR(1)EGARCH(1,1)		AR(1)EGARCH(1,1)		AR(1)EGARCH(1,1)		AR(1)EGARCH(1,1)	
	estimate	*SE*	*estimate*	*SE*	*estimate*	*SE*	*estimate*	*SE*	*estimate*	*SE*	*estimate*	*SE*	*estimate*	*SE*
a_0	0.000	0.001	0.000	0.0008	0.000	0.0012	0.001	0.002	0.002	0.001	0.000	0.002	0.001	0.002
a_1	0.170 **	0.038	-0.088 **	0.0309	0.116 **	0.0315	0.080 *	0.034	-0.031	0.037	-0.015	0.036	-0.006	0.038
ω	-0.091 *	0.045	-0.445 *	0.072	-0.077 *	0.030	-0.138 **	0.053	-0.124 **	0.036	-0.073 *	0.032	-0.081 **	0.031
α_1	0.070 **	0.026	0.545 **	0.175	0.045 *	0.018	0.109 **	0.033	0.075 **	0.023	0.039 *	0.021	0.061 **	0.023
γ_1	0.022	0.015	-0.102	0.063	0.059 **	0.019	0.053 *	0.023	0.010	0.018	0.007	0.016	-0.007	0.016
β_1	0.994 **	0.005	0.955 **	0.009	0.993 **	0.004	0.989 **	0.007	0.989 **	0.004	0.993 **	0.004	0.994 **	0.004
log likelihood	1411.9		1306.2		1388.3		1197.6		1267.7		1227.8		1301.1	
Q(20)	15.584		4.761		27.349		19.699		12.634		15.355		18.577	
p-value	0.742		1.000		0.126		0.477		0.893		0.756		0.549	
$Q^2(20)$	10.040		0.187		38.823		19.878		14.727		22.577		18.067	
p-value	0.967		1.000		0.007		0.466		0.792		0.310		0.583	

Note: ** and * indicate statistical significance at 1% and 5% level, respectively. Q(20) is the Ljung-Box statistic for the null hypothesis that there is no autocorrelation up to order 20 for standardized residuals. $Q^2(20)$ is the Ljung-Box statistic for the null hypothesis that there is no autocorrelation up to order 20 for standardized residuals squared.

Table 3. AR-EGARCH models - Sample B (Dec. 16, 2009 - Mar. 31, 2011)

	Model by Country													
	PG		IR		IL		GR		SP		GM		FR	
	AR(1)EGARCH(1,1)		AR(1)EGARCH(1,1)		AR(1)EGARCH(1,1)		AR(1)EGARCH(1,1)		AR(1)EGARCH(1,1)		AR(1)EGARCH(1,1)		AR(1)EGARCH(1,1)	
	estimate	*SE*	*estimate*	*SE*	*estimate*	*SE*	*estimate*	*SE*	*estimate*	*SE*	*estimate*	*SE*	*estimate*	*SE*
a_0	0.014 **	0.004	0.009 *	0.004	0.002	0.002	0.018 *	0.008	0.005 *	0.003	0.001	0.003	0.000	0.002
a_1	0.169 **	0.055	0.093 **	0.022	0.153 **	0.041	0.034	0.054	0.145 **	0.055	-0.074	0.052	-0.101	0.062
ω	-0.541 **	0.156	-0.106 **	0.033	-0.214 **	0.089	-0.746 *	0.299	-0.985 **	0.363	-11.110 **	0.463	-1.176 *	0.641
α_1	0.403 **	0.098	-0.050	0.039	0.023	0.044	0.438 *	0.190	0.445 **	0.124	0.251 **	0.078	0.238 *	0.102
γ_1	0.195 **	0.061	0.185 **	0.048	0.156 **	0.034	0.063	0.083	0.144 *	0.071	0.014	0.039	-0.071	0.056
β_1	0.945 **	0.025	0.969 **	0.008	0.969 **	0.012	0.822 **	0.090	0.881 **	0.055	-0.785 **	0.072	0.848 **	0.096
log likelihood	278.3		304.9		609.2		112.6		479.1		553.2		613.3	
Q(20)	20.155		17.226		28.088		26.649		28.793		21.719		25.156	
p-value	0.448		0.638		0.107		0.145		0.092		0.356		0.196	
$Q^2(20)$	12.759		2.071		18.726		9.863		14.183		31.695		18.687	
p-value	0.887		1.000		0.540		0.971		0.821		0.047		0.542	

Note: ** and * indicate statistical significance at 1% and 5% level, respectively. Q(20) is the Ljung-Box statistic for the null hypothesis that there is no autocorrelation up to order 20 for standardized residuals. $Q^2(20)$ is the Ljung-Box statistic for the null hypothesis that there is no autocorrelation up to order 20 for standardized residuals squared.

Table 4. Cross-correlation analysis for Portugal based on the approach developed by Hong (2001)

Sample A: (Jan 1, 2007 - Dec. 15, 2009)

	Causality in Mean						Causality in Variance					
Lag	IR	IL	GR	SP	GM	FR	IR	IL	GR	SP	GM	FR
5	6.67 **	17.65 **	27.61 **	34.24 **	35.02 **	1.32	-1.10	-0.85	6.11 **	5.66 **	5.92 **	0.26
10	5.61 **	12.59 **	19.25 **	24.30 **	24.63 **	0.36	-0.70	-1.22	4.01 **	3.24 **	3.80 **	-0.64
15	4.29 **	10.54 **	15.34 **	19.84 **	19.54 **	-0.19	-1.19	-0.17	5.17 **	2.48 **	6.07 **	0.96

Sample B: (Dec. 16, 2009 - Mar. 31, 2011)

	Causality in Mean						Causality in Variance					
Lag	IR	IL	GR	SP	GM	FR	IR	IL	GR	SP	GM	FR
5	2.62 **	2.39 **	5.52 **	7.45 **	0.51	-0.90	-1.20	-0.79	-0.32	-0.41	-0.32	-0.22
10	1.29	1.69 *	3.43 **	5.04 **	0.09	-1.01	0.41	-1.08	-0.61	-0.91	0.99	4.39 **
15	1.60	1.47	2.24 **	3.83 **	0.12	-1.19	-0.48	-1.53	-0.97	-1.29	0.51	2.76 **

Note: Table entries show values of Q-statistic. The Q-statistic is used to test the null hypothesis of no-causality from lag 1 up to lag k (k=5, 10, 15).
If the test statistic is larger than the critical value of the standard normal distribution, the null hypothesis is rejected.
* and ** indicates significance at 5% and 1%, respectively. Q-statistic are based on one-side tests. Lags are measured in days.

Table 5. Cross-correlation analysis for Ireland based on the approach developed by Hong (2001)

Sample A: (Jan 1, 2007 - Dec. 15, 2009)

	Causality in Mean						Causality in Variance					
Lag	PG	IL	GR	SP	GM	FR	PG	IL	GR	SP	GM	FR
5	1.53	-0.80	1.07	2.34 **	3.93 **	-0.08	10.22 **	-0.76	1.62	-1.23	1.62	6.21 **
10	1.27	-0.43	-0.13	1.40	3.91 **	0.06	6.35 **	-1.22	0.13	0.58	0.13	3.42 **
15	0.66	-1.01	-0.62	1.08	2.77 **	-0.56	4.49 **	-1.83 *	-0.63	0.27	-0.63	2.16 *

Sample B: (Dec. 16, 2009 - Mar. 31, 2011)

	Causality in Mean						Causality in Variance					
Lag	PG	IL	GR	SP	GM	FR	PG	IL	GR	SP	GM	FR
5	1.79 *	1.02	1.17	3.45 **	-1.29	-0.57	-0.98	-1.55	-1.12	-1.46	-0.34	-0.59
10	1.17	0.92	1.03	3.14 **	-1.19	-0.46	-1.70 *	-1.60	-1.57	-1.11	1.65 *	2.42 **
15	0.76	0.51	0.61	3.76 **	-1.15	-0.83	-2.09 *	-2.14 *	-1.98 *	-1.65 *	2.10 *	1.50

Note: Table entries show values of Q-statistic. The Q-statistic is used to test the null hypothesis of no-causality from lag 1 up to lag k (k=5, 10, 15).
If the test statistic is larger than the critical value of the standard normal distribution, the null hypothesis is rejected.
* and ** indicates significance at 5% and 1%, respectively. Q-statistic are based on one-side tests. Lags are measured in days.

Table 6. Cross-correlation analysis for Italy based on the approach developed by Hong (2001)

Sample A: (Jan 1, 2007 - Dec. 15, 2009)

	Causality in Mean						Causality in Variance					
Lag	PG	IR	GR	SP	GM	FR	PG	IR	GR	SP	GM	FR
5	-0.62	0.92	2.20 *	4.44 **	1.33	-0.11	-0.41	-1.51	-0.74	-0.90	-0.90	1.36
10	-0.34	-0.25	1.36	3.64 **	0.69	-0.31	-0.63	-2.06 *	-0.61	-0.23	-1.24	1.20
15	-0.16	-0.73	0.81	2.46 **	0.26	0.48	0.96	-2.33 **	-0.45	0.77	-1.48	0.71

Sample B: (Dec. 16, 2009 - Mar. 31, 2011)

	Causality in Mean						Causality in Variance					
Lag	PG	IR	GR	SP	GM	FR	PG	IR	GR	SP	GM	FR
5	3.49 **	2.65 **	0.98	2.97 **	-0.48	1.32	0.63	0.75	0.45	-0.26	3.14 **	-1.24
10	2.52 **	1.33	1.84 *	3.75 **	0.96	0.74	-0.05	0.27	-0.52	-0.61	3.65 **	1.31
15	1.26	0.25	0.92	2.96 **	0.79	0.28	-0.27	-0.49	-0.87	-0.15	2.54 **	0.35

Note: Table entries show values of Q-statistic. The Q-statistic is used to test the null hypothesis of no-causality from lag 1 up to lag k (k=5, 10, 15).
If the test statistic is larger than the critical value of the standard normal distribution, the null hypothesis is rejected.
* and ** indicates significance at 5% and 1%, respectively. Q-statistic are based on one-side tests. Lags are measured in days.

Table 7. Cross-correlation analysis for Greece based on the approach developed by Hong (2001)

Sample A: (Jan 1, 2007 - Dec. 15, 2009)

	Causality in Mean						Causality in Variance					
Lag	PG	IR	IL	SP	GM	FR	PG	IR	IL	SP	GM	FR
5	-0.45	1.13	-0.64	2.39 **	-0.86	-0.66	-0.42	-0.72	3.02 **	2.32 *	-0.05	-0.99
10	0.75	0.69	1.40	2.47 **	-0.83	-0.46	-0.76	-0.94	1.29	1.12	-0.58	-0.98
15	0.47	-0.15	0.56	1.71 *	-1.34	0.01	-0.16	-1.43	8.19 **	1.02	-0.84	-1.08

Sample B: (Dec. 16, 2009 - Mar. 31, 2011)

	Causality in Mean						Causality in Variance					
Lag	PG	IR	IL	SP	GM	FR	PG	IR	IL	SP	GM	FR
5	0.34	-0.29	-0.17	-0.34	0.60	-0.61	-0.70	-0.64	2.01 *	-0.39	-1.24	0.82
10	0.07	-0.74	-0.94	-1.21	0.33	0.17	0.21	-0.39	1.74 *	-0.55	1.27	2.54 **
15	0.64	0.18	0.21	-0.08	0.05	0.23	-0.68	-1.03	0.64	-0.82	1.01	1.48

Note: Table entries show values of Q-statistic. The Q-statistic is used to test the null hypothesis of no-causality from lag 1 up to lag k (k=5, 10, 15).
If the test statistic is larger than the critical value of the standard normal distribution, the null hypothesis is rejected.
* and ** indicates significance at 5% and 1%, respectively. Q-statistic are based on one-side tests. Lags are measured in days.

Table 8. Cross-correlation analysis for Spain based on the approach developed by Hong (2001)

Sample A: (Jan 1, 2007 - Dec. 15, 2009)

	Causality in Mean						Causality in Variance					
Lag	PG	IR	IL	GR	GM	FR	PG	IR	IL	GR	GM	FR
5	-1.24	1.68	-0.91	0.01	3.16 **	-1.40	-0.59	-1.19	-1.29	-1.06	-0.89	0.07
10	0.06	0.72	0.87	-0.28	2.18 *	-0.82	-0.79	-1.54	-1.36	0.35	0.02	0.10
15	0.10	0.08	2.03 *	-0.15	2.27 *	0.01	-0.10	-1.68 *	2.88 **	1.22	-0.45	0.08

Sample B: (Dec. 16, 2009 - Mar. 31, 2011)

	Causality in Mean						Causality in Variance					
Lag	PG	IR	IL	GR	GM	FR	PG	IR	IL	GR	GM	FR
5	2.04 *	1.75 *	0.99	1.23	-0.71	-1.00	-0.44	-1.00	-0.65	0.09	2.32 *	0.22
10	1.48	2.24 *	1.13	1.74 *	-0.17	-0.68	0.05	0.65	0.70	-0.31	1.91 *	1.29
15	0.57	1.20	0.23	0.87	0.06	-0.60	0.04	-0.13	-0.13	-0.68	1.39	0.72

Note: Table entries show values of Q-statistic. The Q-statistic is used to test the null hypothesis of no-causality from lag 1 up to lag k (k=5, 10, 15).
If the test statistic is larger than the critical value of the standard normal distribution, the null hypothesis is rejected.
* and ** indicates significance at 5% and 1%, respectively. Q-statistic are based on one-side tests. Lags are measured in days.

Table 9. Cross-correlation analysis for Germany based on the approach developed by Hong (2001)

Sample A: (Jan 1, 2007 - Dec. 15, 2009)

	Causality in Mean						Causality in Variance					
Lag	PG	IR	IL	GR	SP	FR	PG	IR	IL	GR	SP	FR
5	1.29	-0.45	1.17	-0.04	-0.84	-1.20	-0.83	-0.72	-0.71	0.98	-0.31	1.20
10	1.63	-0.17	1.17	-0.72	-0.54	-1.02	-1.52	-0.94	-1.41	0.54	-1.31	0.60
15	2.20 *	-0.67	2.09 *	-0.31	0.31	0.60	-1.58	-1.43	6.31 **	0.33	-1.37	0.57

Sample B: (Dec. 16, 2009 - Mar. 31, 2011)

	Causality in Mean						Causality in Variance					
Lag	PG	IR	IL	GR	SP	FR	PG	IR	IL	GR	SP	FR
5	-0.41	0.81	2.33 **	4.07 **	0.86	1.74	11.81 **	18.70 **	17.10 **	1.75 *	5.39 **	0.42
10	-0.45	0.32	2.16 *	2.65 **	0.49	0.35	9.38 **	13.37 **	12.64 **	1.34	3.95 **	1.92 *
15	-0.60	0.16	1.35	2.78 **	0.08	-0.15	7.62 **	10.58 **	9.50 **	0.83	2.78 **	1.21

Note: Table entries show values of Q-statistic. The Q-statistic is used to test the null hypothesis of no-causality from lag 1 up to lag k (k=5, 10, 15).
If the test statistic is larger than the critical value of the standard normal distribution, the null hypothesis is rejected.
* and ** indicates significance at 5% and 1%, respectively. Q-statistic are based on one-side tests. Lags are measured in days.

Table 10. Cross-correlation analysis for France based on the approach developed by Hong (2001)

Sample A: (Jan 1, 2007 - Dec. 15, 2009)

	Causality in Mean						Causality in Variance					
Lag	PG	IR	IL	GR	SP	GM	PG	IR	IL	GR	SP	GM
5	-0.85	-0.28	13.32 **	15.45 **	31.69 **	54.05 **	0.70	0.26	1.23	6.50 **	7.70 **	18.41 **
10	-0.08	1.36	8.98 **	10.07 **	22.07 **	37.74 **	0.36	8.15 **	0.77	4.15 **	5.38 **	13.68 **
15	-0.07	0.52	8.72 **	7.76 **	18.03 **	30.40 **	-0.02	6.21 **	0.31	3.28 **	3.67 **	10.75 **

Sample B: (Dec. 16, 2009 - Mar. 31, 2011)

	Causality in Mean						Causality in Variance					
Lag	PG	IR	IL	GR	SP	GM	PG	IR	IL	GR	SP	GM
5	1.26	1.83 *	1.30	-0.30	-0.42	10.99 **	2.54 **	4.91 **	3.05 **	0.59	2.92 **	4.42 **
10	0.11	0.99	0.60	0.37	-0.66	7.47 **	1.40	2.92 **	2.00 *	-0.32	1.46	3.47 **
15	-0.24	0.47	0.12	0.11	-0.62	6.30 **	0.43	1.81 *	0.90	-0.84	0.51	2.40 **

Note: Table entries show values of Q-statistic. The Q-statistic is used to test the null hypothesis of no-causality from lag 1 up to lag k (k=5, 10, 15).
If the test statistic is larger than the critical value of the standard normal distribution, the null hypothesis is rejected.
* and ** indicates significance at 5% and 1%, respectively. Q-statistic are based on one-side tests. Lags are measured in days.